AFML-TR-79-4117

LEVEL II

DETERMINATION OF TEST TECHNIQUE INFLUENCE ON K_{ISCC} VALUES FOR ALUMINUM 7075-T651

AD A077453

John J. Ruschau

University of Dayton Research Institute
300 College Park Avenue
Dayton, Ohio 45469

AUGUST 1979

TECHNICAL REPORT AFML-TR-79-4117
Interim Technical Report January 1978 - April 1979

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David C Watson
DAVID C. WATSON
Engineering and Design Data
Materials Integrity Branch

Clayton Harmsworth
CLAYTON HARMSWORTH
Technical Manager
Engineering and Design Data
Materials Integrity Branch

FOR THE COMMANDER:

Thomas D. Cooper
THOMAS D. COOPER, Chief
Materials Integrity Branch
Systems Support Division
Air Force Materials Laboratory

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFML-TR-79-4117 (18) (19)

2. GOVT ACCESSION NO.:

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): (6) DETERMINATION OF TEST TECHNIQUE INFLUENCE ON K_{ISCC} VALUES FOR ALUMINUM 7075-T651,

5. TYPE OF REPORT & PERIOD COVERED: (9) Interim Technical Report, Jan [redacted]78 — Apr [redacted]79,

6. PERFORMING ORG. REPORT NUMBER: (14) UDR-TR-79-32

7. AUTHOR(s): (10) John J. Ruschau

8. CONTRACT OR GRANT NUMBER(s): (15) F33615-78-C-5002

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
University of Dayton Research Institute
300 College Park Avenue
Dayton, Ohio 45469

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: (16) 2421-03-05 (17) 03

11. CONTROLLING OFFICE NAME AND ADDRESS:
Air Force Materials Laboratory (AFML/MXE)
Wright-Patterson AFB, Ohio 45433

12. REPORT DATE: (11) Aug[redacted]79

13. NUMBER OF PAGES: 23

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (12) 24

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report):

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

18. SUPPLEMENTARY NOTES:

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

aluminum	bolt-loaded
7075-T651	compact type specimen
fracture toughness	K-increasing
stress corrosion cracking	K-decreasing

K sub ISCC

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Threshold stress intensity values for stress corrosion cracking (K_{ISCC}) were determined for aluminum alloy 7075-T651 using two different testing techniques: a constant displacement, decreasing stress intensity technique achieved via a bolt-loaded specimen, and a constant load, increasing stress intensity technique. The test specimen geometry was an ASTM standard 3/4-inch (19 mm) compact type specimen. A constant immersion, → over

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20. Abstract (Concluded)

3.5 percent by weight sodium chloride environment was used for evaluating both techniques. Test times were limited to 2000 hours.

For the test period examined, the constant displacement technique yields an approximately 50 percent higher threshold for corrosion cracking than does the constant load technique. The bolt-loaded technique offers simplicity, is inexpensive, and is a useful technique when used to rank materials as to their relative susceptibility to corrosion cracking; however, caution should be employed when comparing K_{ISCC} values obtained via different test techniques.

PREFACE

This interim technical report was submitted by the University of Dayton Research Institute, Dayton, Ohio, under contract F33615-78-C-5002, "Quick Reaction Evaluation of Materials," with the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. Mr. David Watson, AFML/MXA, was the Laboratory Project Monitor for this program.

This effort was conducted during the period of January 1978 through April 1979. The author, Mr. John J. Ruschau, was responsible for the direction of the program.

The report was submitted by the author in May 1979.

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SUMMARY

The test program was conducted on a single 2-inch (51 mm) thick plate of aluminum alloy 7075-T651. All stress corrosion testing was conducted in a constant immersion, 3.5 percent by weight solution of NaCl, with test time limited to 2,000 hours. The following conclusions were obtained:

1. The threshold stress intensity for stress corrosion cracking for this material was 13.4 KSI$\sqrt{in}$ (14.7 MPa$\sqrt{m}$,) employing a constant displacement, decreasing stress intensity testing method. For a constant load, increasing stress intensity technique, the threshold determined was less than 9 KSI$\sqrt{in}$ (9.9 MPa$\sqrt{m}$).

2. For the given test period, the constant displacement technique yields a nonconservative estimation of this material's sensitivity to corrosion cracking relative to the constant load technique.

3. The constant displacement technique is a convenient and inexpensive test method which lends itself to portability and large scale testing. However, results obtained are sensitive to such parameters as test time period and corrosion product wedging, which can yield erroneous results if not taken into consideration.

SECTION I
INTRODUCTION

Corrosion is a problem that all materials are plagued with if placed in the proper environment. Gold, for example, a seemingly insensitive material under most conditions, will corrode rapidly when placed in a mercury environment, while iron begins to corrode or "rust" immediately upon exposure to a typical air atmosphere. Many materials, when exposed to the joint interaction of a tensile stress and a corrosive medium, undergo the phenomenon of stress corrosion cracking. For aircraft operating in a seacoast atmosphere stress corrosion cracking has been found to significantly reduce the service life of many structural components. Examples of corrosion cracking problems experienced in aircraft have historically been associated with such components as landing gear where sustained loading and continuous environmental exposure have been known to produce catastrophic failures on quiescent aircraft. Because of the ever-increasing usage of new materials in the aerospace industry, it is necessary to thoroughly document these materials' susceptibility to stress corrosion cracking.

The use of linear-elastic fracture mechanics principles to categorize materials as to their sensitivity to corrosion cracking has met with considerable success and is reported extensively in recent technical literature. These concepts have involved stressing a precracked specimen in some environment and determining a threshold stress intensity value, K_{ISCC}, below which stress corrosion cracking will not occur. Since there exists no standard test method yet which employs these fracture mechanics principles, specimen configuration and test methods vary for each laboratory. The American Society for Testing and Materials Committee on Fracture Testing, Subcommittee on Subcritical Crack Growth (ASTM-E24-04), has recently conducted a test program on 4340 steel investigating both the specimen geometry and test technique influence on the value of K_{ISCC} (results

unpublished at this time). The purpose of this program reported herein is to similarly study stress corrosion cracking testing methodology but for a different material and different testing conditions.

The material employed in this investigation was aluminum alloy 7075. A T651 heat treatment was used because of its relatively high susceptibility to stress corrosion cracking. Two variations of loading an ASTM standard 3/4-inch (19 mm) compact type (CT) specimen were examined: a constant load, increasing stress intensity technique which models real life situations for most cases, and a constant displacement, decreasing stress intensity technique, achieved by wedging open a precracked CT specimen by means of properly torquing a bolt in one arm of the specimen. For both techniques a continuous exposure in a 3.5 percent by weight sodium chloride solution was employed.

SECTION II
MATERIAL AND SPECIMENS

A single rolled plate of aluminum alloy 7075-T651, 2.0 inches (50 mm) thick was procured with nominal dimensions of 12 x 12 inches (308 x 308 mm). A chemical analysis was performed on the as-received material with the results listed in the table below. Also presented are the chemical composition limits of aluminum 7075 as defined in Federal Specification QQ-A-250/12B.

CHEMICAL COMPOSITION OF 7075 TEST PLATE
(Wt. %)

Zinc	Magnesium	Copper	Chromium	Silicon	Manganese	Iron	Titanium
5.8	2.4	1.5	0.19	0.14	0.02	0.24	0.04

CHEMICAL COMPOSITION LIMITS FOR 7075*
(Wt. %)

Zinc	Magnesium	Copper	Chromium	Silicon	Manganese	Iron	Titanium
5.1-6.1	2.1-2.9	1.2-2.0	0.18-0.40	0.50	0.30	0.70	0.20

* Values are maximum unless range is given.

The composition of the test plate is well within the ranges listed for aluminum 7075 and, with the slight exception of iron, also meets the specifications for aluminum 7175, an improved "cleaner" version of 7075 specifically designed for forging applications. Photomicrographs taken from the principal directions of the test plate are presented in Figure 1.

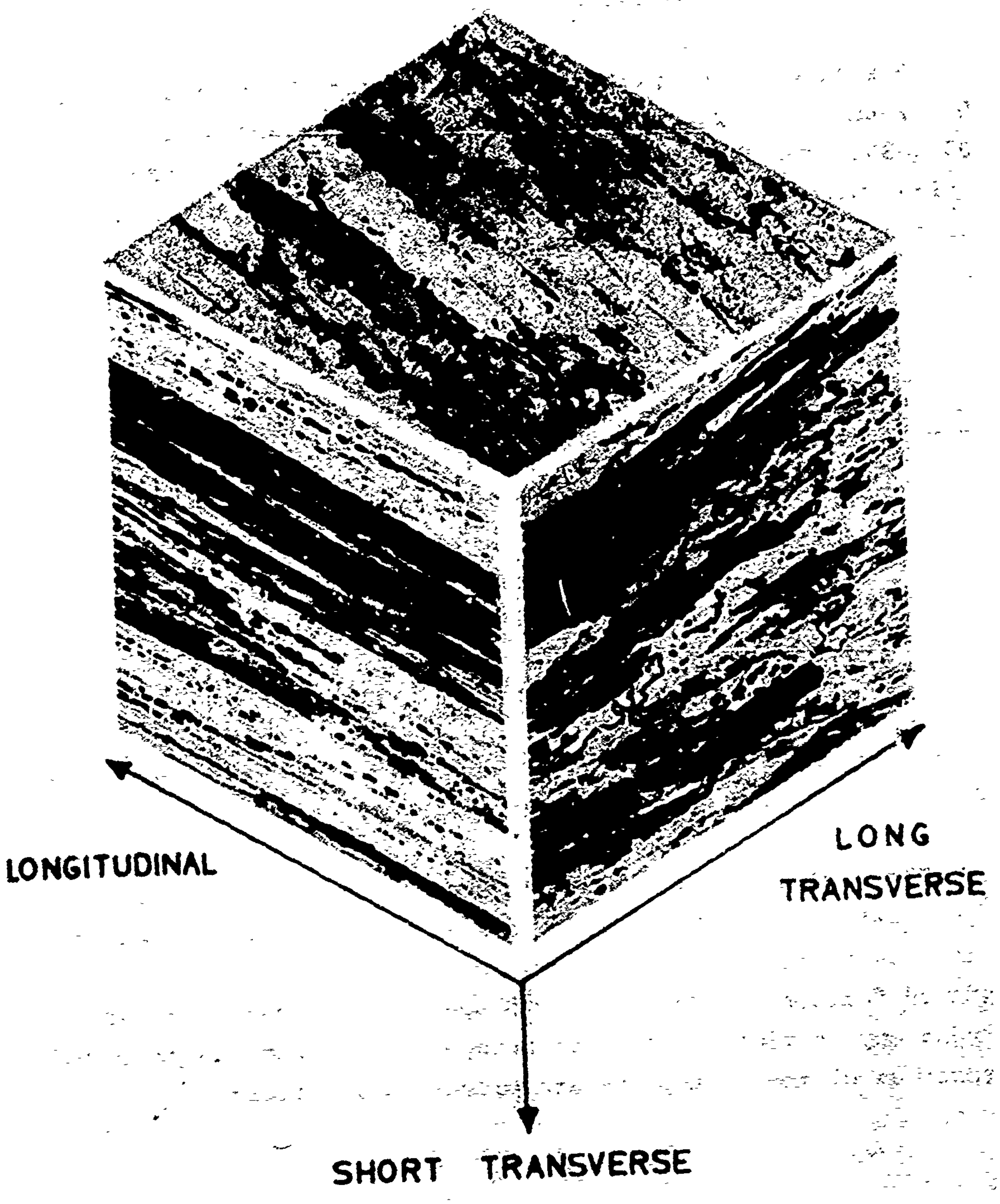
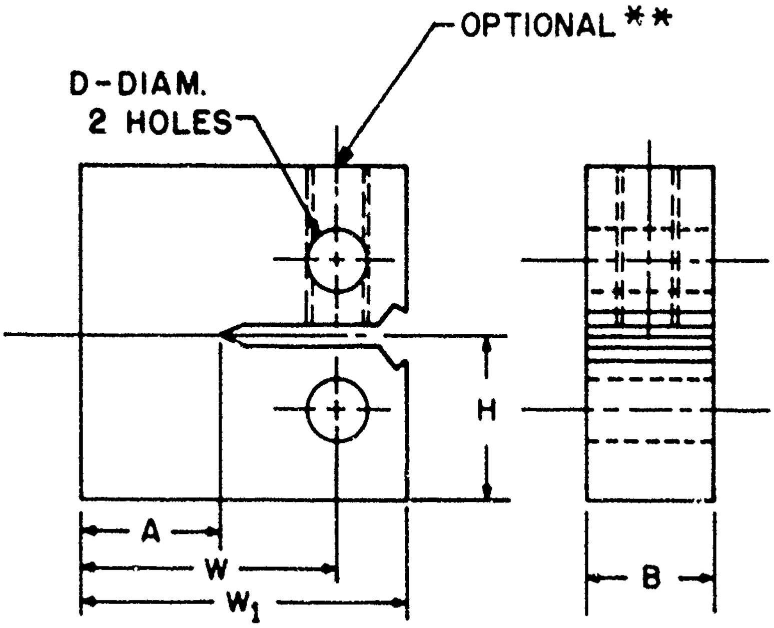


Figure 1. Aluminum Alloy 7075-T651 Microstructure (150X).

Fracture toughness and stress corrosion specimens were machined to the dimensions illustrated in Figure 2. For the constant displacement (bolt-loaded) specimens a hole was drilled and tapped in one arm of the specimen to accommodate a 0.375-16 UNC aluminum bolt used to stress the specimen. All fracture toughness and stress corrosion specimens were machined in the short transverse-longitudinal (S-L) orientation of the plate as defined in ASTM Standard E399.



DIMENSIONS *

SPECIMEN THICKNESS	A	B	W	W_1	H	D
3/4 (19.05)	0.915 (23.2)	0.750 (19.05)	1.500 (38.10)	1.875 (47.63)	0.900 (22.86)	0.375 (9.53)

* DIMENSIONS IN INCHES (mm)

** 0.375 -16 UNC THD. FOR BOLT - LOADED SPECIMENS.

Figure 2. Fracture Toughness and Stress Corrosion Cracking Test Specimens.

SECTION III
PROCEDURES

Fracture toughness testing was accomplished with a Baldwin-Weidemann testing machine following guidelines set fort in ASTM Standard E399, Plane Strain Fracture Toughness on Metallic Materials. Fatigue precracking was performed on an MTS closed-loop, electro-hydraulic fatigue testing machine. All specimens were precracked to a crack-length-to-specimen-width ratio (a/W) of approximately 0.5. Final maximum stress intensity used during precracking operations was limited to 6.5 KSI$\sqrt{\text{in}}$ (7.4 MPa$\sqrt{\text{m}}$) to avoid any retardation effects on the stress corrosion testing.

The test solution employed for the stress corrosion testing was a 3.5 percent by weight sodium chloride (NaCl) solution with an initial pH reading of approximately 6.5. The two methods of loading investigated in this program are outlined in the following sections.

3.1 CONSTANT LOAD METHOD

Precracked compact type specimens were loaded via a clevis and pin-type arrangement in a vertical loading Satec stress-rupture testing machine which applied load to the specimen with dead weights acting through a lever arm. Clevises and pins were machined from aluminum to minimize any galvanic coupling effects. An environmental chamber was fashioned from a one-gallon plastic container which enclosed the specimen. The specimen was then completely submerged in the test solution and the test load applied. Lab air was bubbled through the solution for the duration of the test to prevent any solute from precipitating out, as well as to supply oxygen to the corrosive medium. Periodically distilled water was added to replenish the water lost to evaporation. After 1,000 hours of test the entire solution was drained out and a fresh solution added.

Upon failure, defined as complete separation of the specimen, the specimens were removed and the initial stress-intensity recorded along with time to failure. If no failure was experienced after 2,000 hours, the test was terminated, the specimen broken apart, the fracture face examined for crack growth, and the initial stress intensity accurately determined.

3.2 CONSTANT DISPLACEMENT METHOD

The constant displacement or bolt-loaded test method employs a bolt of the same material as the test specimen (again to avoid galvanic corrosion effects) to apply an initial stress intensity. See Figure 3. After initial stressing the specimens were submerged in the test environment for a 2,000-hour test duration. Upon completion of the exposure period the specimen was removed and the final stress intensity, after crack extension, was computed. Since this is a crack arrest method, the final stress intensity computed is the assumed threshold value for stress corrosion cracking.

Before the specimens were preloaded the necessary compliance data was obtained. A fatigue crack was grown to various lengths and at each length a trace of specimen crack opening displacement (COD) versus load was obtained. Typical traces of COD vs. load obtained from a single specimen are presented in Figure 4. The data derived in this manner was then rearranged in the form of a series of curves as illustrated in Figure 5. Utilizing this compliance data, an initial stress intensity was applied by wedging open the crack with the bolt.

Precracked compact type specimens with a standard clip-on gage in place were initially loaded to stress intensities equal to approximately 85 percent of the plane strain fracture toughness value by properly torquing the bolt until the desired COD, corresponding to the desired stress condition, was reached. The bolt tip was machined to a gentle radius to achieve point loading. Before and during torquing, a few drops of the test solution were placed at the crack tip so that the solution would be drawn into the crack as it opened. After the proper COD was

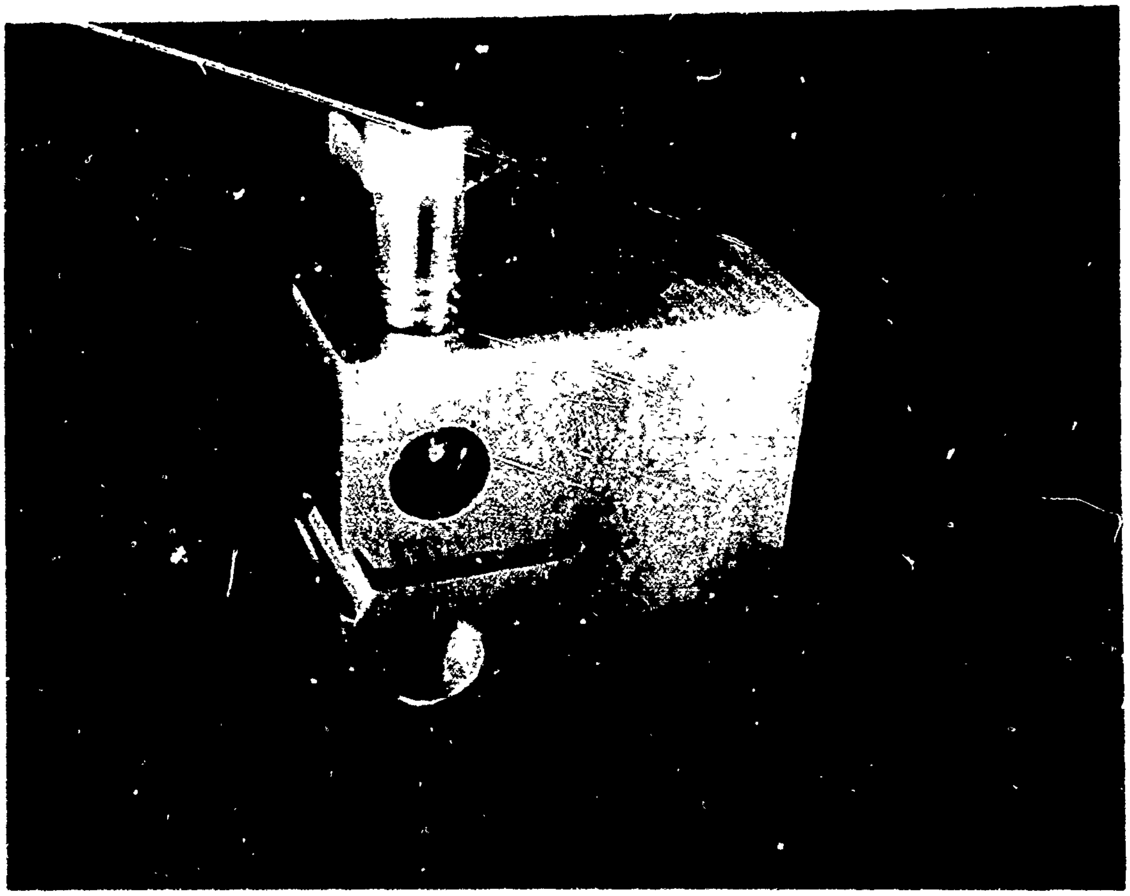


Figure 3. Bolt-Loaded Stress Corrosion Cracking Test Sample.

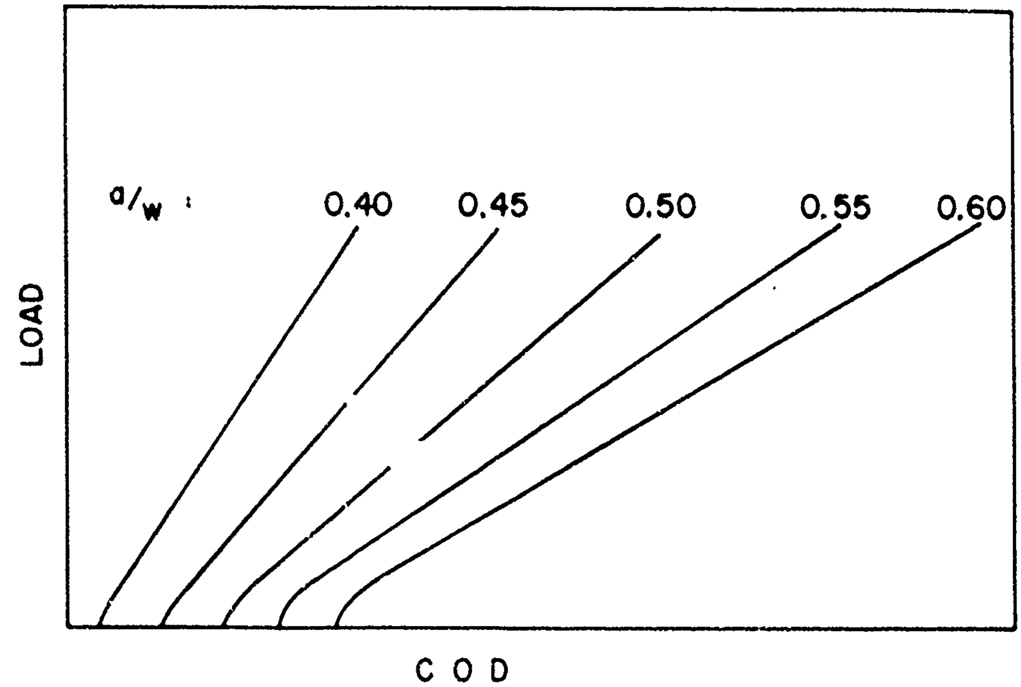


Figure 4. Typical Load Versus Crack Opening Displacement Traces.

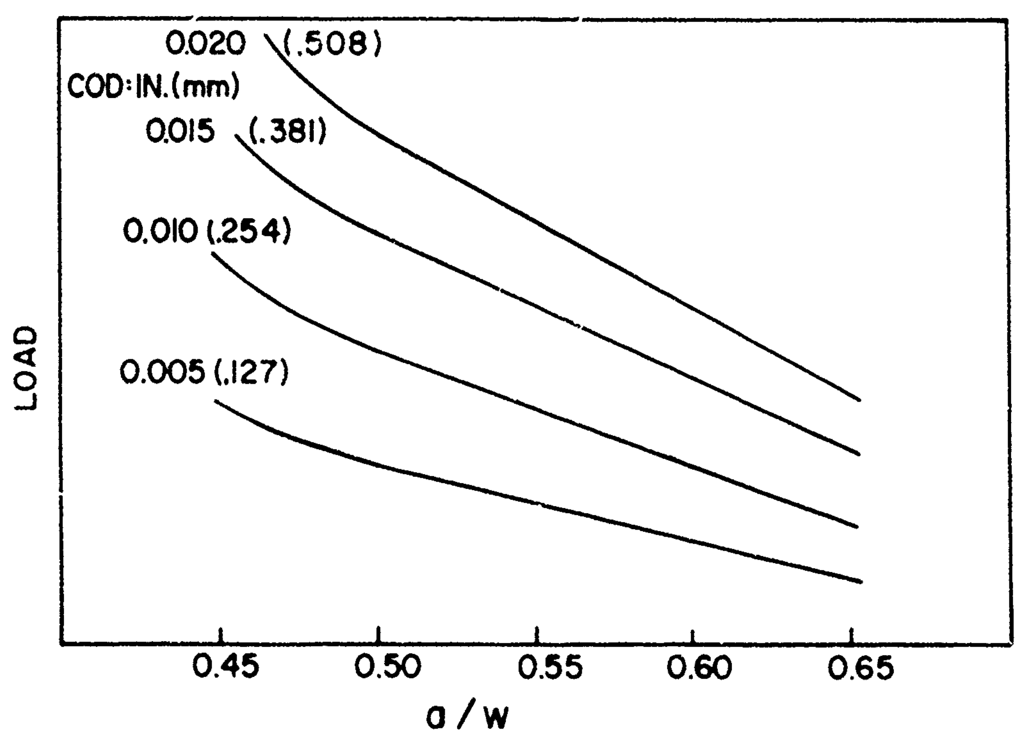


Figure 5. Compliance Curve Obtained for Bolt-Loaded Specimen.

reached, as indicated by the clip gage, the gage was removed and COD verified with a toolmaker's microscope. The specimen was then placed in an environmental chamber. The portion of the specimen containing the bolt was coated with paraffin to avoid any contact of the bolt tip with the solution as any corrosion build-up at the bolt tip could possibly wedge the specimen open further than desired. As with the previously mentioned constant load technique, air was bubbled through the solution, and the chamber drained and refilled with a fresh solution after 1,000 hours of test.

After the 2,000-hour exposure period the specimens were removed and the COD again measured. The bolt was then carefully removed and the specimen loaded in a Tinius-Olsen tensile test machine with the clip gage in place. A trace of load versus COD was obtained until complete specimen fracture, quite similar to the test procedure for fracture toughness testing. Afterwards, the load corresponding to the COD value created by the bolt at the conclusion of the corrosion test and the final crack length were determined and used to calculate the final stress intensity at crack arrest. This value for stress intensity is defined as the threshold for stress corrosion cracking in a decreasing stress intensity field.

SECTION IV
RESULTS AND DISCUSSION

Fracture toughness test results for short transverse-longitudinal (S-L) oriented specimens yielded an average toughness value of 18.4 KSI$\sqrt{in}$ (20.2 MPa$\sqrt{m}$). These results are in good agreement with reference literature.[1,2]

The stress corrosion cracking results obtained for both test methods are illustrated in the computer-prepared curve presented in Figure 6. The data points corresponding to the bolt-loaded test results represent the arrest stress intensities calculated after 2,000 hours in test solution. Since the crack lengths for these specimens were not monitored throughout the test, it is not known whether these threshold stress intensity values actually represent a condition of absolute crack arrest. Therefore, the results obtained for this technique, and similarly for the K-increasing technique, must be qualified as results obtained for a test duration of 2,000 hours. However, for the test period investigated, results for the two methods differ greatly. The bolt-loaded, decreasing stress intensity technique yielded an average threshold value of 13.4 KSI$\sqrt{in}$ (14.7 MPa$\sqrt{m}$), while the constant load, increasing stress intensity technique yielded a threshold stress intensity value of approximately 9.0 KSI$\sqrt{in}$ (9.89 MPa$\sqrt{m}$). Upon removal of the bolts for the constant displacement technique, the specimen COD did not return to the initial zero displacement as determined prior to beginning the test [0.0095 inch (0.241 mm) loading versus 0.006 inch (0.152 mm) unloading], indicating a possibility of corrosion product

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[1] Sprowls, D.O., et al., Evaluation of Stress-Corrosion Cracking Susceptibility Using Fracture Mechanics Techniques, Alcoa Research Laboratories, May 1973.

[2] Staley, J.T., Investigation to Develop a High Strength Stress-Corrosion Resistant Naval Aircraft Aluminum Alloy, Alcoa Research Laboratories, November 1970.

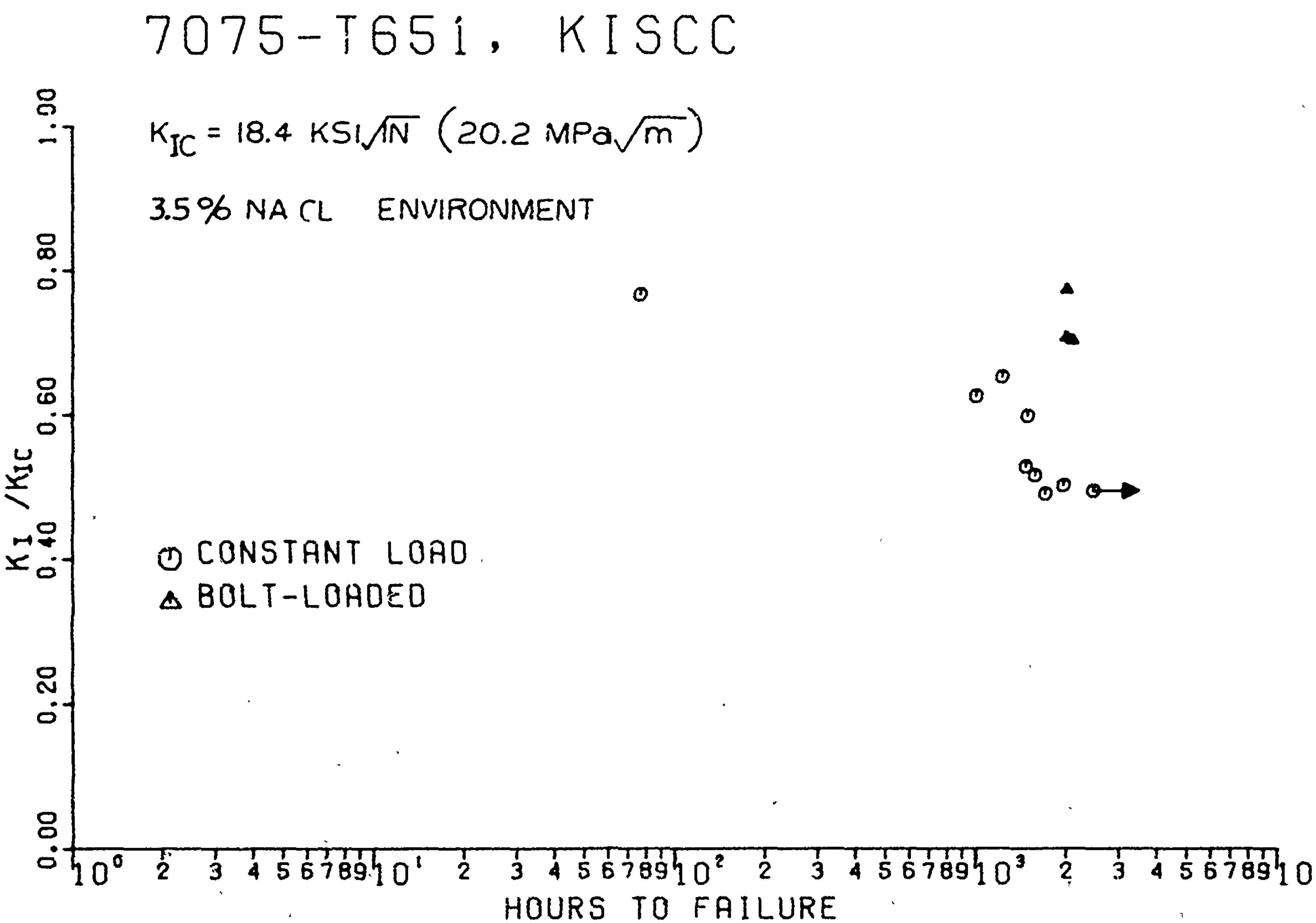

Figure 6. Stress Corrosion Cracking Results for Aluminum Alloy 7075-T651.

build-up on the fracture faces. The effect of such a corrosion build-up may result in an increase in specimen stress intensity and therefore an increase in crack extension; thus these threshold results might be yet higher if corrosion wedging had not taken place since the crack extension would be less. For the constant load specimen which did not fail after 2,400 hours (indicated by the runout arrow) when loaded at an initial stress intensity of 9.0 KSI$\sqrt{in}$ (9.89 MPa$\sqrt{m}$), there was evidence of considerable crack extension. When the test was terminated, the calculated final stress intensity was approximately 14.5 KSI$\sqrt{in}$ (15.9 MPa$\sqrt{m}$) indicating failure was inevitable. Thus, it appears that prolonging the test period would also yield a lower threshold value for this type of loading. Reference literature[3] estimates a threshold stress intensity for this material under similar loading conditions of approximately 7 KSI$\sqrt{in}$ (7.7 MPa$\sqrt{m}$).

The bolt-loaded technique clearly offers advantages over the constant load technique in that it is a simple, low-cost, portable design which lends itself to large volume testing. Since this specimen is self-loading, it can be placed in practically any environment, without tying up any equipment. Although beyond the scope of this test program, the self-loaded specimen offers a more convenient means to obtain stress corrosion cracking rate characteristics, since it can be removed from the test environment and the crack tip observed rather easily. However, this technique yields nonconservative results for this material when compared to the more cumbersome and costlier constant load technique. Deviations for the two techniques might be explained under the following two hypotheses. Although the precracked specimens were prepared in similar manners, the initial loading conditions differed. For the bolt-loaded specimens the initial stress intensity applied was approximately

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[3] Hyatt, M.V. and Speidel, M.O., Stress Corrosion Cracking of High Strength Aluminum Alloys, Boeing D6-24840, June 1970.

85 percent of the material's fracture toughness, while for the constant load specimens the initial stress intensities were in general lower. Due to the difference in the level of initial stress conditions, it is possible the crack incubation periods might likewise differ, i.e., the time spent for the crack in the specimen to change from a transgranular (fatigue) mode to an intergranular (corrosion cracking) mode and progress through the crack tip plastic zone. This phenomenon would cause differences in results if the tests were terminated prematurely.

Secondly, since the bolt-loaded technique is a decreasing stress intensity condition and if crack tip velocity is proportional to stress intensity, the crack growth rate will decrease with increasing crack extension. For some materials crack extension may continue indefinitely. Thus for this material, a 2,000-hour time period may not have been sufficient to produce a crack arrest or near-arrest condition. Test periods of 10,000 hours or more might yield a better (or worse) correlation between methods if time would permit; however, for the time period investigated, the constant displacement techniq plied to this material must be labeled as yielding noncons vative results.

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1. Sprowls, D.O., et al., Evaluation of Stress-Corrosion Cracking Susceptibility Using Fracture Mechanics Techniques, Alcoa Research Laboratories, May 1973.

2. Staley, J.T., Invesitgation to Develop a High Strength Stress-Corrosion Resistant Naval Aircraft Aluminum Alloy, Alcoa Research Laboratories, November 1970.

3. Hyatt, M.V. and Speidel, M.O., Stress Corrosion Cracking of High Strength Aluminum Alloys, Boeing D6-24840, June 1970.

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